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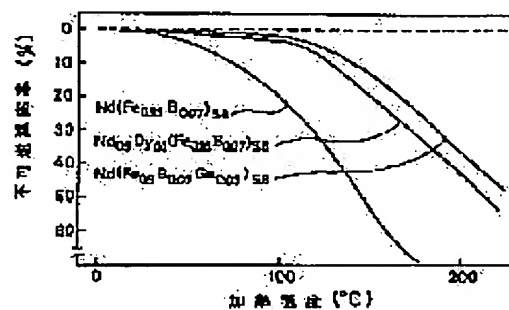
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(54) SINTERED PERMANENT MAGNET WITH EXCELLENT HEAT STABILITY

(57)Abstract:

PROBLEM TO BE SOLVED: To remarkably improve I_Hc and provide a sintered permanent magnet with highly excellent heat stability by providing a magnet wherein the major phase is formed of $R_2Fe_{14}B$ type inter-metal compound, intrinsic coercive force (I_Hc) increases and Curie temperature (T_c) slightly reduces by Ga content, and the contained Ga forms a liquid phase with a rare earth rich phase which surrounds the major phase in sintering.

SOLUTION: A magnet is expressed by the following formula R by atomic ratio; $R(Fe_{1-x-y-z-u}Co_xByGa_zMu)A$ (R is a combination of at least one of Nd, Pr, Ce and other rare earth elements, and M is a combination of at least one of Nb, W, V, Ta and Mo, $0 < x \leq 0.7$, $0.02 \leq y \leq 0.3$, $0 < z \leq 0.15$, $0 \leq u \leq 0.1$, $4.0 \leq A \leq 7.5$), the major phase is $R_2Fe_{14}B$ type inter-metal compound, and intrinsic coercive force (I_Hc) is increased and Curie temperature (T_c) is reduced by Ga content. The Ga contained at sintering forms a liquid phase with a rare earth rich phase and the magnet is sintered.



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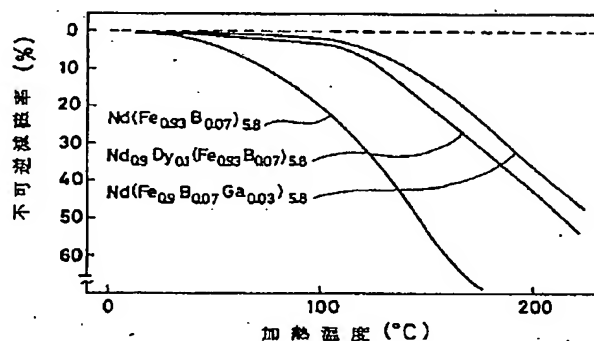
(54)【発明の名称】 熱安定性の良好な焼結型永久磁石

(57)【要約】

【課題】 主相が $R_2Fe_{14}B$ 型金属間化合物であり、

Gaの含有により固有保磁力(IHc)が増大しキュリー温度(Tc)がやや低下する作用を有し、含有されるGaが焼結時において主相を取り囲む希土類リッチ相とともに液相を形成して焼結されることによってIHcを著しく高め、極めて良好な熱安定性を付与した焼結型永久磁石を提供する。

【解決手段】 原子比で式 $R(Fe_{1-x-y-z-u}Co_xByGa_zMu)_A$ (ここでRはNd, Pr, Ceその他の希土類元素の1種以上の組み合わせ、MはNb, W, V, Ta, Moの1種以上の組み合わせ、 $0 < x \leq 0.7$ 、 $0.02 \leq y \leq 0.3$ 、 $0 < z \leq 0.15$ 、 $0 \leq u \leq 0.1$ 、 $4.0 \leq A \leq 7.5$)で表され、主相が $R_2Fe_{14}B$ 型金属間化合物であり、Gaの含有により固有保磁力(IHc)が増大しキュリー温度(Tc)が低下する作用を有し、焼結時において含有されるGaが希土類リッチ相とともに液相を形成し焼結されたことを特徴とする熱安定性の良好な焼結型永久磁石。



【特許請求の範囲】

【請求項1】 原子比で式 $R(Fe_{1-x-y-z-u}Co_xByGa_zMu)_A$ （ここでRはNd, Pr, Ceその他の希土類元素の1種または2種以上の組み合わせ、MはNb, W, V, Ta, Moの1種または2種以上の組み合わせ、 $0 < x \leq 0.7$ 、 $0.02 \leq y \leq 0.3$ 、 $0 < z \leq 0.15$ 、 $0 \leq u \leq 0.1$ 、 $4.0 \leq A \leq 7.5$ ）で表され、主相が $R_2Fe_{14}B$ 型金属間化合物であり、Gaの含有により固有保磁力（IHC）が増大しキュリー点（Tc）が低下する作用を有し、焼結過程において含有されるGaが希土類リッチ相とともに液相を形成し焼結されてなることを特徴とする熱安定性の良好な焼結型永久磁石。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】本発明は、主相が $R_2Fe_{14}B$ 型金属間化合物であり、Gaの含有により固有保磁力（IHC）が増大しキュリー点（Tc）が低下する作用を有し、含有されるGaが焼結過程においてリッチ相とともに液相を形成し焼結されてなることによりIHCを著しく高め、極めて良好な熱安定性を付与した焼結型永久磁石に関する。

【0002】

【従来の技術】R-Fe-B系永久磁石材料は、R-Co系永久磁石材料よりも高い磁気特性が得られる新しい組成系として開発が進んでおり、数多くの発明が提案されている。例えばNd₁₅Fe₇₇B₈〔組成式表示でNd(Fe_{0.91}B_{0.09})_{5.67}〕は最大磁気エネルギー積（BH）maxが35MG0e、固有保磁力IHCが10K0eに達する磁気特性を得ている（J. Appl. Phys. 55(6)2083(1984)参照。）

しかしながら、開発初期に提案されたR-Fe-B系永久磁石はキュリー点（Tc）が低く、そのため熱安定性が悪いという欠点がある。すなわち、従来のR-Co系の永久磁石では約800℃のTcを有するのに対し、開発初期に提案されたR-Fe-B系永久磁石材料では通常Tcが約300℃程度であり、最高でも370℃程度と極めて低い（特開昭59-46008号公報参照）。従って、熱安定性が不十分であって、周囲温度が高い環境下での使用には難点があった。それを解決する手段としては、直接Tcを向上させること、室温における固有保磁力（IHC）を十分高くすることによって高温での減磁分があっても耐えられるようにすることの2つが知られている。

【0003】前者として、Feの一部をCoで置換することによってTcを上げる試みがなされた。その結果、Tcを400℃以上で、磁気特性を犠牲にすれば800℃にまでも上昇させる効果が認められた（特開昭59-64733号公報参照）。後者として、Al, Ti, V, Cr, Mn, Zn, Hf, Nb, Ta, Mo, Ge, Sb, Sn, Bi, Ni等の添加が行われてきた。中でもAlはIHC

向上に特に有効とされる（特開昭59-89401号、60-77960号公報参照）。さらにTb, Dy, Hoのような重希土類元素によるNdの一部置換が高い最大エネルギー積

〔（BH）max〕を保持しつつIHCを改善するために提案されており、約30MG0eの（BH）maxのときIHCが9K0e程度のものが12～18K0eに増大される（特開昭60-32306、60-34005号公報参照）。加えて、CoとAlの複合添加が熱安定性向上の手段として提案されている。すなわち、Feの一部をCoで置換するとTcは向上するが、反面IHCの低下が否めない。それは、Nd（Fe, Co）₂で表わされる磁性を持った析出物が結晶粒界に現われ逆磁区が発生してIHCを低下するためと考えられている。そこで、CoにAlを複合添加することによって非磁性のNd（Fe, Co, Al）₂で表わされる相を出現させることによって逆磁区を発生させない試みも行われている（Appl. Phys. Lett. 48(19), 1309(1986)）。

【0004】

【発明が解決しようとする課題】しかし、前述の従来技術には次に述べる問題点がある。

①CoによるFeの一部置換の場合

結晶磁気異方性を低下させるためIHCを低下する。また、原料面からコスト高、供給不安がある。

②Al, Ti, V, Ni等を添加する場合

Niを除いて非磁性材料であるため、多量の添加は残留磁束密度 $4\pi Ir$ の低下を招来し、（BH）maxを下げる。Niも、強磁性材料ではあるが磁気モーメントが小さいため、結局 $4\pi Ir$ を低下する。

③重希土類元素を添加する場合

非常に高価であるためコストの著しい上昇を伴う。資源的希少性に加えて永久磁石以外の用途が少ないためである。

④CoとAlを複合添加する場合

Alの添加はTcを著しく低下させるため、100℃以上における高温での熱安定性に劣る。加えて、CoとAlを複合添加したR-Fe-B系磁石のIHCは、たかだか12K0e程度にすぎない。

【0005】従って、本発明の課題は、主相が $R_2Fe_{14}B$ 型金属間化合物であり、Gaの含有により固有保磁力（IHC）が増大しキュリー温度（Tc）が低下する作用を有し、含有されるGaが焼結時において主相を取り囲む希土類リッチ相とともに液相を形成して焼結されることによってIHCを著しく高め、極めて良好な熱安定性を付与した焼結型永久磁石を提供することである。

【0006】

【課題を解決するための手段】上記従来の課題を解決した本発明は、原子比で式 $R(Fe_{1-x-y-z-u}Co_xByGa_zMu)_A$ （ここでRはNd, Pr, Ceその他の希土類元素の1種または2種以上の組み合わせ、MはNb, W, V, Ta, Moの1種または2種以上の組み合わ

せ、 $0 < x \leq 0.7$ 、 $0.02 \leq y \leq 0.3$ 、 $0 < z \leq 0.15$ 、 $0 \leq u \leq 0.1$ 、 $4.0 \leq A \leq 7.5$ で表され、主相が $R_2Fe_{14}B$ 型金属間化合物であり、Gaの含有により固有保磁力(IHc)が増大しキュリー点(Tc)が低下する作用を有し、焼結過程において含有されるGaが主相を取り囲む希土類リッチ相とともに液相を形成し焼結されてなることを特徴とする熱安定性の良好な焼結型永久磁石である。上記、本発明磁石において、 $0 < x \leq 0.7$ 、 $0.02 \leq y \leq 0.3$ 、 $0.001 \leq z \leq 0.15$ 、 $0 \leq u \leq 0.1$ 、 $4.0 \leq A \leq 7.5$ とすることが熱安定性の点からより好ましい。また、 $0 < x \leq 0.39$ 、 $0.03 \leq y \leq 0.2$ 、 $0.002 \leq z \leq 0.1$ 、 $0.002 \leq u \leq 0.04$ 、 $4.5 \leq A \leq 7$ とすることが熱安定性の向上の点から特に好ましい。また、RがNdで $u=0$ の場合、 $0 < x \leq 0.39$ 、 $0.03 \leq y \leq 0.2$ 、 $0.002 \leq z \leq 0.1$ 、 $4.5 \leq A \leq 7$ とすることが良好な熱安定性を得るために好ましい。

【0007】希土類元素RはNd、Pr、Ceその他の希土類元素であって、特にNdを主体としてPr、Ceのような軽希土類元素またはDyのような重希土類元素で一部置換できる。なお、Ho、Tbなどの重希土類元素も利用できる。

Ndの一部をPrで置換する場合には原子比率で98%を越えると $4\pi Ir$ が低下し、Ndの一部をCeで置換する場合には、原子比率で30%を越えると $4\pi Ir$ が低下する。Ndの一部をDyで置換する場合には原子比率で3%未満ではIHc向上効果すなわち熱安定性がなく、5%以上25%以下の置換によって最も好ましい効果があるが、40%を越える置換は $4\pi Ir$ を低下するため好ましくない。

【0008】本発明において、硼素Bの含有量yが0.02未満だとTcが低くなり、かつ十分な保磁力が得られない。他方、yが0.3を超えると $4\pi Is$ が低下し、磁気特性に悪影響を及ぼす相が出現する。従って、yは0.02~0.3であり、より好ましくは0.03~0.2、最も好ましくは0.04~0.15である。

【0009】本発明において、Gaの添加はIHc向上に顕著な効果がある。この効果はR-Fe-B系磁石の主相(金属間化合物Nd₂Fe₁₄B等。)を取り囲むR

リッチ相と密接に関係があると考えられる。Gaの含有量zは良好な熱安定性を確保するために $0 < z \leq 0.15$ とするのがよく、 $0.001 \leq z \leq 0.15$ とするのがより好ましく、 $0.002 \leq z \leq 0.10$ とするのがさらに好ましく、 $0.005 \leq z \leq 0.05$ とすることが特に好ましい。Gaの含有量zが0.15を超えると飽和磁化 $4\pi Is$ とTcの著しい減少を呈し好ましくない。

【0010】本発明において、Coは必須であり、Tc向上効果があるためGaと複合添加することによって熱安定性の際だった向上に効果がある。xで示されるCo

の含有量が0.7を超えると磁石の $4\pi Ir$ 、IHcが低下して好ましくない。IHcと $4\pi Ir$ およびTcの良好な均衡のためのCoの好ましい上限は0.39であり、最も好ましくは0.25である。

【0011】本発明磁石には、添加元素M: Nb, W, V, Ta, Moを結晶粒の粗大化防止のために添加することができる。なかでも、NbとWの効果が最も優れている

。Nbの添加は $4\pi Ir$ を若干低下するが、Gaほど $4\pi Ir$ を低下させない。また、Nbは耐蝕性向上にも効果があるため、比較的高温にさらされる高耐熱永久磁石にとって非常に有効な元素である。原子比で式 $R(Fe_{1-x-y-z-u}Co_xByGa_zMu)_A$ (ここでRは希土類元素の1種または2種以上の組み合わせ、MはNb, W, V, Ta, Moの1種または2種以上の組み合わせ、 $0 < x \leq 0.7$ 、 $0.02 \leq y \leq 0.3$ 、 $0 < z \leq 0.15$ 、 $0 \leq u \leq 0.1$ 、 $4.0 \leq A \leq 7.5$)で表され、MがNbであり含有量uが0.001未満のときはIHcの十分な向上効果が得られず、また、十分な耐蝕性を示さない。他方、0.1を超えると $4\pi Ir$ とTcの好ましくない減少を招来する。Nbのより好ましい範囲は0.002~0.04である。Wの添加も熱安定性を著しく向上する。uで示されるWの量が0.1を超えると、 $4\pi Is$ およびIHcが著しく低下する。そして、0.001未満のときはIHcの十分な向上効果が得られない。より好ましい範囲は0.002~0.04である。V, Ta, Moの添加も有効であり、uが0.001未満のときには十分なIHc向上効果が得られず、0.1を超えると $4\pi Is$ が著しく減少する。より好ましい範囲は0.002~0.04である。

【0012】本発明において、Aが4未満のときは $4\pi Is$ が低く、7.5を超えるとFeとCoリッチな相が出現し、保磁力を著しく低下させる。従って、Aは4~7.5であり、より好ましくは4.5~7、最も好ましくは5.0~6.8である。

【0013】

【発明の実施の形態】以下、実施例により本発明を説明する。

【0014】(実施例1) Nd($Fe_{0.70}Co_{0.2}B_{0.07}Mo_{0.03}$)_{6.5}(ただし、M=B, Al, Si, P, Ti, V, Cr, Mn, Cu, Ga, Ge, Zr, Nb, Mo, Ag, In, Sb, Wのいずれか1種)なる組成の合金をアーク溶解にて作製した。得られたインゴットをスタンプミルおよびディスクミルで粗粉砕した。粉砕媒体としてN₂ガスを用いジェットミルで微粉砕を行い粉砕粒度 $3.5\mu m$ (FSSS)の微粉砕粉を得た。得られた原料粉を15K0eの磁場中で横磁場成形(プレス方向と磁場方向が直交)した。成形圧力は2t/cm²であった。本成形体を真空中で1090℃×2時間焼結した。熱処理は500~900℃に1時間加熱保持した後、急冷した。

得られた結果を表1に示す。検討した19元素の中でI Hcが10K0eを超えるものはGaだけである。このようにGaは保磁力の向上に非常に有効である。表1において、本発明に属するM=Ga添加の場合のTc=468℃に対し、M=B添加のもののTc=477℃であり、*

*Gaの含有によってTcがやや低下する作用を有していることがわかる。

【0015】

【表1】

Nd (Fe_{0.7} Co_{0.2} B_{0.07} M_{0.04})_{0.5} 磁石の磁気特性

M	B	Al	Si	P	Ti	V	Cr	Mn	Ni	Cu
4πIs (KG)	13.31	12.61	12.80	12.90	12.77	13.19	12.30	12.50	12.95	12.57
4πIr (KG)	12.80	12.45	12.65	0	11.80	13.05	12.15	12.34	12.78	12.32
iHc (KOe)	2.6	8.5	7.0	0	4.8	4.9	5.1	5.3	4.1	3.0
(BH) max (MGOe)	13	33.5	32.0	0	24.0	25.5	28.0	24.0	13.1	18.1
Tc (℃)	477	460	458	482	467	470	478	431	485	481

Tc:キュリー点

M	Ga	Ge	Zr	Nb	Mo	Ag	In	Sb	W
4πIs (KG)	12.60	12.72	12.30	13.03	13.10	13.22	12.70	12.05	12.95
4πIr (KG)	12.50	~0	10.5	12.9	~0	~0	~0	~0	12.75
iHc (KOe)	16.0	~0	4.3	6.9	~0	~0	~0	~0	6.0
(BH) max (MGOe)	35.0	~0	12.1	35.1	~0	~0	~0	~0	32.2
Tc (℃)	468	479	466	477	465	483	488	482	476

【0016】(実施例2) Nd (Fe_{0.9-x} Co_x B_{0.07} Ga_{0.03})_{0.5} (x=0~0.75) および比較例としてNd (Fe_{0.93-x} Co_x B_{0.07})_{0.5} (x=0~0.25)、Nd_{0.9} Dy_{0.1} (Fe_{0.93-x} Co_x B_{0.07})_{0.5} (x=0~0.25) なる組成の合金を実施例1と同様な方法で粗粉碎、微※

※粉碎、焼結、熱処理した。得られた結果を表2、表3、表4に示す。これらの結果からCoの添加量xは0.7以下で適当であることがわかる。

【0017】

【表2】

Nd (Fe_{0.9-x} Co_x B_{0.07} Ga_{0.03})_{0.5} 磁石の磁気特性

磁気特性 \ x	0	0.01	0.05	0.25	0.39	0.7	0.75
4πIr (KG)	12.6	12.58	12.55	12.09	12.02	10.7	9.2
iHc (KOe)	20.6	19.9	19.6	16.5	14.8	12.3	11.0
(BH) max (MGOe)	37.0	36.6	36.2	33.2	32.8	26.6	19.2

【0018】

【表3】

Nd (Fe_{0.93-x} Co_x B_{0.07})_{0.5} 磁石の磁気特性 (比較例)

磁気特性 \ x	0	0.01	0.05	0.25
4πIr (KG)	13.4	13.32	13.32	12.88
iHc (KOe)	9.0	8.8	8.8	7.1
(BH) max (MGOe)	42.1	41.5	41.5	38.8

【0019】

【表4】

Nd_{0.9} Dy_{0.1} (Fe_{0.93-x} Co_x B_{0.07})_{0.5} 磁石の磁気特性 (比較例)

磁気特性 \ x	0	0.01	0.05	0.25
4πIr (KG)	12.62	12.59	12.51	12.11
iHc (KOe)	15.6	15.4	15.0	11.6
(BH) max (MGOe)	38.2	37.9	37.5	34.3

【0020】次に、Co量が0および0.2の場合における試料を所定温度に30分間加熱保持後、open fluxの変化を測定し、熱安定性を調べた。測定に用いた試料はパーミアンス係数 $\mu_c = -2$ となる形状に加工したものである。得られた結果を図1、図2に示す。明らかにGaを加えると保磁力が高く熱安定性は非常に改善される。

【0021】(実施例3) Nd(Fe_{0.7}Co_{0.2}B_{0.08}Ga_{0.02})_A (A=3.7~7.7)、Nd(Fe_{0.92}B_{0.08})_A (A=5.6~6.6)なる組成の合金を実施例1と同様な方法で粗粉碎、微粉碎、焼結、熱処理した。得られた結果を表5(a)、表5(b)に示す。Nd-*

*Fe-B3元系の場合、A=6.2以上においては $I_H c$ 、(BH)_{max}はほとんどゼロであるのに対し、Co、Gaを複合添加することにより、A=6.6以上でも高保磁力が得られ、高特性が得られる。Nd-Fe-B3元系は、A=6.2以上においてはNdの酸化により焼結過程で液相として働くNdリッチ相が減少することが原因となつて、保磁力の発生を妨げている。これに対し、Co、Ga複合添加の場合、Gaが酸化したNdの代りに液相として働き、高保磁力を発生させている。

【0022】

【表5】

(a) Nd(Fe_{0.7}Co_{0.2}B_{0.08}Ga_{0.02})_A 磁石の磁気特性

磁気特性 \ A	3.7	4.0	5.6	6.6	7.5	7.7
$4\pi I_r$ (KG)	9.2	10.4	12.25	12.7	13.8	14.0
$I_H c$ (KOe)	17.5	17.3	15.4	12.0	10.7	5.9
(BH) _{max} (MGOe)	19.2	25.0	35.8	37.1	45.6	15.8

(b) Nd(Fe_{0.92}B_{0.08})_A 磁石の磁気特性(比較例)

磁気特性 \ A	5.6	5.8	6.0	6.2	6.4	6.6
$4\pi I_r$ (KG)	13.04	13.2	13.4	13.6	13.7	13.8
$I_H c$ (KOe)	10.0	9.3	9.0	0	0	0
(BH) _{max} (MGOe)	40.2	41.3	42.6	0	0	0

【0023】(実施例4) (Nd_{0.8}Dy_{0.2})(Fe_{0.86-z}Co_{0.06}B_{0.08}Ga_z)_{5.5} (z=0~0.18)なる合金を実施例1と同様な方法で溶解、粉碎、成形、焼結した。さらに、900℃×2時間の加熱保持後、1.5℃/minで常温まで冷却した後、580℃×1時間の時効処理をAr気流中で行い水中で冷却した。得られた磁気特性を表6に示し、220℃加熱による不可逆減磁率を表7に示す。Gaの添加により $4\pi I_r$ 、(BH)_{max}は低下していくが $I_H c$

※ $I_H c$ は大幅に上昇し、耐熱性も向上していることがわかる。Gaの添加量zは0.001で効果が認められ、0.15を越えると $4\pi I_r$ が顕著に減少するので $0 < z \leq 0.15$ が好ましく、 $0.001 \leq z \leq 0.15$ とするのがより好ましく、 $0.002 \leq z \leq 0.10$ とするのがさらに好ましく、 $0.005 \leq z \leq 0.05$ とすることが特に好ましい。

【0024】

【表6】

z	$4\pi I_r$ (G)	$I_H c$ (Oe)	$I_H c$ (Oe)	(BH) _{max} (MGOe)
0	11050	10700	22500	29.5
0.001	11000	10650	23200	29.6
0.002	10900	10600	23500	28.8
0.005	10740	10400	25200	27.9
0.01	10600	10200	26500	27.2
0.05	9400	9600	27200	20.1
0.10	8900	8600	> 28000	18.9
0.15	8000	7800	> 28000	15.3
0.18	7200	7600	> 28000	11.0

【0025】

【表7】

$$(Nd_{0.9} Dy_{0.1}) (Fe_{0.845-z} Co_{0.06} B_{0.08} Nb_{0.015} Ga_z)_{5.5}$$

z	220℃加熱による不可逆減磁率(%, Pc = -2)
0	10.1
0.001	9.3
0.002	7.5
0.005	5.1
0.01	2.7
0.05	1.9
0.10	0.3
0.15	0.1
0.18	0.1

【0026】(実施例5) $(Nd_{0.9} Dy_{0.1}) (Fe_{0.845-z} Co_{0.06} B_{0.08} Nb_{0.015} Ga_z)_{5.5}$ ($z=0\sim 0.06$) なる合金を実施例1と同様な方法で溶解、粉碎、成形、焼結、熱処理した。得られた磁気特性を表8に示し、220℃加熱による不可逆減磁率を表9に示す。Dy置換量の少ない場合においてもGaの添加により熱安定性は向上することがわかる。また、Gaの添加量は0.001で効果が認められ、0.15を越えると $4\pi I_r$ が著しく*

*減少することがわかる。従って、Gaの添加量zは $0 < z \leq 0.15$ が好ましく、 $0.001 \leq z \leq 0.15$ とするのがより好ましく、 $0.002 \leq z \leq 0.10$ とするのがさらに好ましく、 $0.005 \leq z \leq 0.05$ とすることが特に好ましいことがわかる。

【0027】

【表8】

$$(Nd_{0.9} Dy_{0.1}) (Fe_{0.845-z} Co_{0.06} B_{0.08} Nb_{0.015} Ga_z)_{5.5}$$

z	$4\pi I_r$ (G)	BH_c (Oe)	$1H_c$ (Oe)	(BH) _{max} (MGOe)
0	11850	11550	15200	34.1
0.001	11800	15200	16700	33.8
0.002	11670	11440	17400	32.4
0.005	11580	11260	18760	32.0
0.01	11400	11000	19800	31.6
0.05	10550	10100	> 28000	26.9
0.10	10000	9880	> 28000	25.2
0.15	8550	8320	> 28000	22.4
0.18	7560	7240	> 28000	20.8

【0028】

【表9】

$$(Nd_{0.9} Dy_{0.1}) (Fe_{0.845-z} Co_{0.06} B_{0.08} Nb_{0.015} Ga_z)_{5.5}$$

z	220℃加熱による不可逆減磁率(%, Pc = -2)
0	38.1
0.001	34.4
0.002	32.6
0.005	29.7
0.01	20.3
0.05	0.7
0.10	0.6
0.15	0.6
0.18	0.5

【0029】

【発明の効果】以上、実施例に示したように、従来のR-Fe-B系焼結磁石においては含有される希土類元素Rの酸化により焼結過程で液相として働くRリッチ相が減少することが原因となって有効な未酸化の含有R分が不足した状態で焼結されるために保磁力が著しく減少するのに対し、本発明磁石においては焼結過程において未酸化の有効な含有R分の不足を補うように含有されてい

るGaが液相として存在し焼結が進行するために極めて高い $1H_c$ を発現し際立って良好な熱安定を獲得することができる。

【図面の簡単な説明】

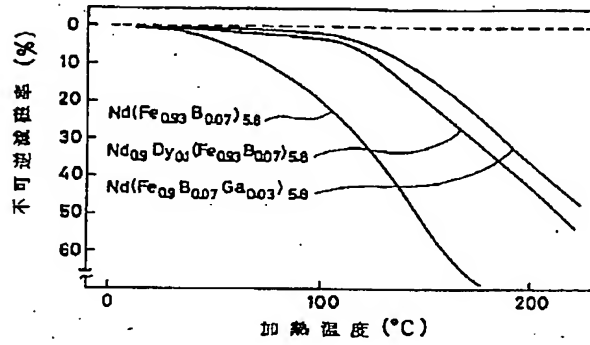
【図1】Nd-Fe-B、Nd-Dy-Fe-BおよびNd-Fe-B-Ga磁石の加熱温度に対する不可逆減磁率を示す図である。

【図2】Nd-Fe-Co-B、Nd-Dy-Fe-C

11

o-BおよびNd-Fe-Co-B-Ga磁石の加熱温

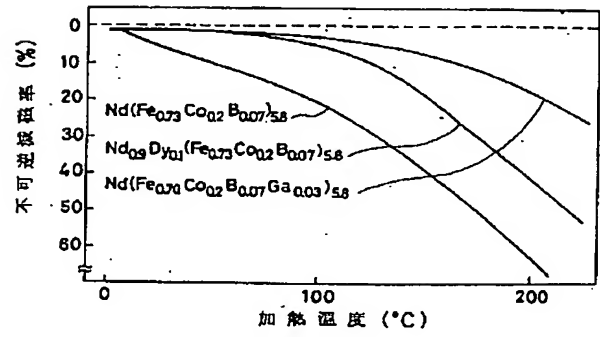
【図1】



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度に対する不可逆減磁率を示す図である。

【図2】



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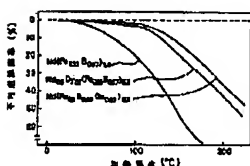
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(54) SINTERED PERMANENT MAGNET WITH EXCELLENT HEAT STABILITY



(57)Abstract:

PROBLEM TO BE SOLVED: To remarkably improve IHc and provide a sintered

permanent magnet with highly excellent heat stability by providing a magnet wherein the major phase is formed of R₂Fe₁₄B type inter-metal compound, intrinsic coercive force (I_{Hc}) increases and Curie temperature (T_c) slightly reduces by Ga content, and the contained Ga forms a liquid phase with a rare earth rich phase which surrounds the major phase in sintering.

SOLUTION: A magnet is expressed by the following formula R by atomic ratio; R(Fe_{1-x-y-z-u}CoxByGazMu)A (R is a combination of at least one of Nd, Pr, Ce and other rare earth elements, and M is a combination of at least one of Nb, W, V, Ta and Mo, 0<x≤0.7, 0.02≤y≤0.3, 0<z≤0.15, 0≤u≤0.1, 4.0≤A≤7.5), the major phase is R₂Fe₁₄B type inter-metal compound, and intrinsic coercive force (I_{Hc}) is increased and Curie temperature (T_c) is reduced by Ga content. The Ga contained at sintering forms a liquid phase with a rare earth rich phase and the magnet is sintered.

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CLAIMS

[Claim(s)]

[Claim 1] an atomic ratio -- formula $R(Fe_{1-x-y-z-u}Co_xByGa_zMu)_A$ (here -- R -- one sort or two sorts or more of combination of the rare earth elements of Nd, Pr, and Ce and others --) M One sort or two sorts or more of combination of Nb, W, V, Ta, and Mo, It is expressed with $0 < x \leq 0.7$, $0.02 \leq y \leq 0.3$, $0 < z \leq 0.15$, $0 \leq u \leq 0.1$, and $4.0 \leq A \leq 7.5$. The main phase is an $R_2Fe_{14}B$ mold intermetallic compound, and it has the operation to which proper coercive force (I_H) increases by content of Ga, and the Curie point (T_c) falls. The good sintering mold permanent magnet of the thermal stability characterized by Ga contained in a sintering process forming the liquid phase with a rare earth rich phase, and coming to be sintered.

[Translation done.]

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DETAILED DESCRIPTION

[Detailed Description of the Invention]

[0001]

[Field of the Invention] This invention has the operation to which the main phase is an $R_2Fe_{14}B$ mold intermetallic compound, proper coercive force (IHc) increases by content of Ga, and the Curie point (Tc) falls, by Ga to contain forming the liquid phase with R rich phase, and coming to sinter it in a sintering process, raises IHc remarkably and relates to the sintering mold permanent magnet which gave very good thermal stability.

[0002]

[Description of the Prior Art] Development is progressing as a new presentation system from which magnetic properties with a R-Fe-B system permanent magnet ingredient more expensive than a R-Co system permanent magnet ingredient are acquired, and much invention is proposed. For example, as for Nd(Fe_{0.91}B_{0.09})_{5.67}, maximum magnetic energy (product BH) max has acquired the magnetic properties to which 35MGOe(s) and the proper coercive force IHc reach 10KOe(s) by the Nd₁₅Fe₇₇B₈[empirical formula display (J. Appl. Phys. 55(6) 2083 (1984) reference.)].

However, the R-Fe-B system permanent magnet proposed in early stages of development has low therefore the fault [Curie point / (Tc)] that thermal stability is bad. Namely, with the R-Fe-B system permanent magnet ingredient proposed in early stages of development to having about 800-degree C Tc in the

permanent magnet of the conventional R-Co system, T_c is usually about 300 degrees C, and it is very low as about 370 degrees C (refer to JP,59-46008,A). Therefore, thermal stability was inadequate and there was a difficulty in use under the environment where ambient temperature is high. Two of enabling it to bear even if there is a demagnetized part in an elevated temperature as a means to solve it, raising direct T_c and by making sufficiently high proper coercive force (I_H) in a room temperature are known.

[0003] The attempt which raises T_c by permuting a part of Fe by Co as the former was made. Consequently, the effectiveness that also until would raise it at 800 degrees C above 400 degrees C if magnetic properties are sacrificed for T_c was accepted (refer to JP,59-64733,A). As the latter, addition of aluminum, Ti, V, Cr, Mn, Zn, Hf, Nb, Ta, Mo, germanium, Sb, Sn, Bi, nickel, etc. has been performed. aluminum is confirmed to the improvement in I_H especially (refer to JP,59-89401,A and a No. 77960 [60 to] official report). a part of Nd by heavy-rare-earth element still like Tb, Dy, and Ho -- it is proposed in order to improve I_H , holding a maximum energy product $[(BH)_{max}]$ with a high permutation, and that whose I_H is 9KOe extent at the time of $(BH)_{max}$ of about 30 MGOe(s) increases to 12-18KOe (refer to JP,60-32306,A and a No. 34005 [60 to] official report). In addition, compound addition of Co and aluminum is proposed as a means of the improvement in thermal stability. That is, although T_c will improve if a part of Fe is permuted by Co, the fall of the opposite side I_H cannot be denied. It is considered for a sludge with the magnetism expressed with $Nd(Fe, Co)_2$ appearing in the grain boundary, and a reverse magnetic domain's occurring, and falling I_H . Then, the attempt which does not generate a reverse magnetic domain is also performed by making the phase expressed with nonmagnetic $Nd(Fe, Co, aluminum)_2$ to Co by carrying out compound addition of the aluminum appear (Appl. Phys.Lett.48(19), 1309 (1986)).

[0004]

[Problem(s) to be Solved by the Invention] However, there is a trouble described below in the above-mentioned conventional technique.

** In order [of Fe by Co] to reduce a crystal magnetic anisotropy in part in the case of a permutation, fall I_Hc . Moreover, there are cost quantity and supply anxiety from a raw material side.

** Except for nickel, when adding Al, Ti, V, nickel, etc., since it is a non-magnetic material, a lot of addition invites the fall of residual magnetic flux density $4\pi I_r$, and lowers $(BH)_{max}$. Although nickel is also a ferromagnetic ingredient, since the magnetic moment is small, $4\pi I_r$ is fallen after all.

** When adding a heavy-rare-earth element, since it is very expensive, it is accompanied by the remarkable rise of cost. In addition to resource-scarcity, it is because there are few applications other than a permanent magnet.

** When carrying out compound addition of Co and the aluminum, addition of aluminum is inferior to the thermal stability in the elevated temperature in 100 degrees C or more in order to reduce T_c remarkably. in addition, I_Hc of the R-Fe-B system magnet which carried out compound addition of Co and the aluminum - - at most -- it is only 12K Oe extent.

[0005] Therefore, the technical problem of this invention is offering the sintering mold permanent magnet which raised I_Hc remarkably and gave very good thermal stability by forming the liquid phase and being sintered with the rare earth rich phase in which the main phase is an $R_2Fe_{14}B$ mold intermetallic compound, and Ga which has the operation to which proper coercive force (I_Hc) increases by content of Ga, and Curie temperature (T_c) falls, and is contained encloses the main phase at the time of sintering.

[0006]

[Means for Solving the Problem] this invention which solved the above-mentioned conventional technical problem -- an atomic ratio -- formula $R(Fe_{1-x-y-z-u}Co_xByGa_zMu)$ A (here -- R -- one sort or two sorts or more of combination of the rare earth elements of Nd, Pr, and Ce and others --) M One sort or two sorts or more of combination of Nb, W, V, Ta, and Mo, It is expressed with $0 < x \leq 0.7$, $0.02 \leq y \leq 0.3$, $0 < z \leq 0.15$, $0 \leq u \leq 0.1$, and $4.0 \leq A \leq 7.5$. The main phase is an $R_2Fe_{14}B$ mold intermetallic compound, and it has the operation to

which proper coercive force (IHc) increases by content of Ga, and the Curie point (Tc) falls. Ga contained in a sintering process is the good sintering mold permanent magnet of the thermal stability characterized by forming the liquid phase with the rare earth rich phase which encloses the main phase, and coming to be sintered. In the above and this invention magnet, it is more desirable from the point of thermal stability to be referred to as $0 < x \leq 0.7$, $0.02 \leq y \leq 0.3$, $0.001 \leq z \leq 0.15$, $0 \leq u \leq 0.1$, and $4.0 \leq A \leq 7.5$. Moreover, it is desirable especially from the point of improvement in thermal stability to be referred to as $0 < x \leq 0.39$, $0.03 \leq y \leq 0.2$, $0.002 \leq z \leq 0.1$, $0.002 \leq u \leq 0.04$, and $4.5 \leq A \leq 7$. Moreover, it is desirable in order that it may obtain good thermal stability that R sets to $0 < x \leq 0.39$, $0.03 \leq y \leq 0.2$, $0.002 \leq z \leq 0.1$, and $4.5 \leq A \leq 7$ by Nd in the case of $u = 0$.

[0007] Rare earth elements R are the rare earth elements of Nd, Pr, and Ce and others, and a light-rare-earth element like Pr and Ce or a heavy-rare-earth element like Dy can permute them in part by making especially Nd into a subject. In addition, heavy-rare-earth elements, such as Ho and Tb, can also be used. If it exceeds 98% at the rate of an atomic ratio in permuting a part of Nd by Pr, in 4pirl's falling and permuting a part of Nd by Ce, if 30% is exceeded at the rate of an atomic ratio, 4pirl will fall. In permuting a part of Nd by Dy, at less than 3%, there is no improvement effectiveness in IHc, i.e., thermal stability, at the rate of an atomic ratio, there is most desirable effectiveness by 25% or less of permutation 5% or more, but the permutation exceeding 40% is not desirable in order it to fall 4pirl.

[0008] In this invention, if the content y of Boron B is less than 0.02, Tc will become low and sufficient coercive force will not be acquired. On the other hand, if y exceeds 0.3, 4pils will fall, and the phase which has a bad influence on magnetic properties appears. therefore, $y \sim 0.02-0.3$ -- it is -- more -- desirable -- 0.03 to 0.2 -- it is 0.04-0.15 most preferably.

[0009] In this invention, addition of Ga has effectiveness remarkable in the improvement in IHc. It is thought that relation has this effectiveness closely with

R rich phase which encloses the main phases (intermetallic-compound $\text{Nd}_2\text{Fe}_{14}\text{B}$ etc.) of a R-Fe-B system magnet. In order to secure good thermal stability, the content z of Ga is good to be referred to as $0 < z \leq 0.15$, it is more desirable to be referred to as $0.001 \leq z \leq 0.15$, and especially the thing set to $0.005 \leq z \leq 0.05$ is [it is still more desirable to be referred to as $0.002 \leq z \leq 0.10$, and] desirable [the content]. It presents a remarkable reduction of T_c as saturation magnetization $4\pi I_r$ and is not desirable if the content z of Ga exceeds 0.15.

[0010] In this invention, Co is indispensable, and since there is the improvement effectiveness in T_c , effectiveness is in the improvement which it was at the time of thermal stability by carrying out compound addition with Ga. if the content of Co shown by x exceeds 0.7 -- magnetic $4\pi I_r$ -- I_r and I_Hc fall and are not desirable. It reaches $4\pi I_r$ with I_Hc , and the desirable upper limit of Co for good balance of T_c is 0.39, and is 0.25 most preferably.

[0011] To this invention magnet, alloying element M: Nb, and W, V, Ta and Mo can be added for big and rough-ized prevention of crystal grain. Especially, the effectiveness of Nb and W is most excellent. Although addition of Nb falls $4\pi I_r$ a little, Ga does not reduce $4\pi I_r$. Moreover, since Nb has effectiveness also in corrosion-resistant improvement, it is a very effective element for the high heatproof permanent magnet comparatively exposed to an elevated temperature. an atomic ratio -- formula $\text{R}(\text{Fe}_{1-x-y-z-u}\text{Co}_x\text{ByGa}_z\text{Mu})\text{A}$ (here -- R -- one sort or two sorts or more of combination of rare earth elements --) M One sort or two sorts or more of combination of Nb, W, V, Ta, and Mo, It is expressed with $0 < x \leq 0.7$, $0.02 \leq y \leq 0.3$, $0 < z \leq 0.15$, $0 \leq u \leq 0.1$, and $4.0 \leq A \leq 7.5$, M is Nb, when a content u is less than 0.001, sufficient improvement effectiveness of I_Hc is not acquired, and sufficient corrosion resistance is not shown. On the other hand, when exceeding 0.1, reduction which is not desirable as for T_c is invited as $4\pi I_r$. The more desirable range of Nb is 0.002-0.04. Addition of W also improves thermal stability remarkably. When the amount of W shown by u exceeds 0.1, it reaches $4\pi I_r$ and I_Hc falls remarkably. And sufficient improvement effectiveness

of I_{Hc} is not acquired at the time less than of 0.001. More desirable range is 0.002-0.04. Addition of V, Ta, and Mo is also effective, when u is less than 0.001, sufficient improvement effectiveness in I_{Hc} is not acquired, but when exceeding 0.1, $4\pi I_{Hc}$ decreases remarkably. More desirable range is 0.002-0.04.

[0012] the time of $4\pi I_{Hc}$ being low and exceeding 7.5 in this invention, when A is less than four -- Fe and Co -- a rich phase appears and coercive force is reduced remarkably. therefore, A -- 4-7.5 -- it is -- more -- desirable -- 4.5-7 -- it is 5.0-6.8 most preferably.

[0013]

[Embodiment of the Invention] Hereafter, an example explains this invention.

[0014] (Example 1) $Nd(Fe_{0.70}Co_{0.2}B_{0.07}M_{0.03})_{6.5}$ (however, $M=B$, any one sort of aluminum, Si, P, Ti, V, Cr, Mn, Cu, Ga, germanium, Zr, Nb, Mo, Ag, In, Sb, and the W) -- the alloy of a presentation was produced by the arc dissolution.

Coarse grinding of the obtained ingot was carried out by the stamp mill and the disc mill. It pulverized with the jet mill, using N_2 gas as tumbling media, and pulverizing powder with a grinding grain size of 3.5 micrometers (FSSS) was obtained. Horizontal magnetic field shaping (the press direction and the direction of a magnetic field intersect perpendicularly) of the obtained raw material powder was carried out all over the magnetic field of 15KOe(s). $2t$ /of compacting pressure was [cm] 2. This Plastic solid was sintered in the vacuum for 1090 degree-Cx 2 hours. At 500-900 degrees C, heat treatment was quenched, after carrying out heating maintenance for 1 hour. The obtained result is shown in Table 1. That to which I_{Hc} exceeds 10KOe(s) in 19 examined elements is only Ga. Thus, Ga is very effective in improvement in coercive force. In Table 1, to $T_c=468$ degree C in the $M=Ga$ addition belonging to this invention, it is $T_c=477$ degree C of the thing of $M=B$ addition, and it turns out that it has the operation to which T_c falls a little by content of Ga.

[0015]

[Table 1]

Nd (Fe_{0.7} Co_{0.2} B_{0.07} M_{0.03})_{5.8} 磁石の磁気特性

M	B	Al	Si	P	Ti	V	Cr	Mn	Ni	Cu
4πIs (KG)	13.31	12.61	12.80	12.90	12.77	13.19	12.30	12.50	12.95	12.57
4πIr (KG)	12.80	12.45	12.65	0	11.80	13.05	12.15	12.34	12.78	12.32
iHc (KOe)	2.6	8.5	7.0	0	4.8	4.9	5.1	5.3	4.1	3.0
(BH) _{max} (MGOe)	13	33.5	32.0	0	24.0	25.5	28.0	24.0	13.1	18.1
Tc (°C)	477	460	458	482	467	470	478	431	485	481

Tc : キュリー点

M	Ga	Ge	Zr	Nb	Mo	Ag	In	Sb	W
4πIs (KG)	12.60	12.72	12.30	13.03	13.10	13.22	12.70	12.05	12.95
4πIr (KG)	12.50	~ 0	10.5	12.9	~ 0	~ 0	~ 0	~ 0	12.75
iHc (KOe)	16.0	~ 0	4.3	6.9	~ 0	~ 0	~ 0	~ 0	6.0
(BH) _{max} (MGOe)	35.0	~ 0	12.1	35.1	~ 0	~ 0	~ 0	~ 0	32.2
Tc (°C)	468	479	466	477	465	483	488	482	476

[0016] (Example 2) as Nd (Fe_{0.9-x}CoxB_{0.07}Ga_{0.03})_{5.8} (x=0-0.75) and the example of a comparison -- Nd (Fe_{0.93-x}CoxB_{0.07})_{5.8} (x=0-0.25) and Nd_{0.9}Dy_{0.1} (Fe_{0.93-x}CoxB_{0.07})_{5.8} (x=0-0.25) -- the alloy of a presentation -- the same approach as an example 1 -- coarse grinding -- it pulverized, sintered and heat-treated. The obtained result is shown in Table 2, Table 3, and Table 4. These results show that the addition x of Co is suitable or less by 0.7.

[0017]

[Table 2]

Nd (Fe_{0.9-x} Co_x B_{0.07} Ga_{0.03})_{5.8} 磁石の磁気特性

磁気特性 \ x	0	0.01	0.05	0.25	0.39	0.7	0.75
4πIr (KG)	12.6	12.58	12.55	12.09	12.02	10.7	9.2
iHc (KOe)	20.6	19.9	19.6	16.5	14.8	12.3	11.0
(BH) _{max} (MGOe)	37.0	36.6	36.2	33.2	32.8	26.6	19.2

[0018]

[Table 3]

Nd (Fe_{0.93-x}Co_xB_{0.07})_{5.8} 磁石の磁気特性 (比較例)

磁気特性 \ x	0	0.01	0.05	0.25
4πIr (KG)	13.4	13.32	13.32	12.88
1Hc (KOe)	9.0	8.8	8.8	7.1
(BH) _{max} (MGOe)	42.1	41.5	41.5	38.8

[0019]

[Table 4]

Nd_{0.9}Dy_{0.1}(Fe_{0.93-x}Co_xB_{0.07})_{5.8} 磁石の磁気特性 (比較例)

磁気特性 \ x	0	0.01	0.05	0.25
4πIr (KG)	12.62	12.59	12.51	12.11
1Hc (KOe)	15.6	15.4	15.0	11.6
(BH) _{max} (MGOe)	38.2	37.9	37.5	34.3

[0020] Next, they are after heating maintenance and open for 30 minutes to predetermined temperature about a sample in case the amounts of Co(es) are 0 and 0.2. Change of flux was measured and thermal stability was investigated. The sample used for measurement processes the configuration used as permeance coefficient Pc=-2. The obtained result is shown in drawing 1 and drawing 2. If Ga is added clearly, coercive force will be high and thermal stability will improve very much.

[0021] (Example 3) Nd (Fe_{0.7}Co_{0.2}B_{0.08}Ga_{0.02}) -- A (A=3.7-7.7) and Nd (Fe_{0.92}B_{0.08}) -- A (A=5.6-6.6) -- the alloy of a presentation -- the same approach as an example 1 -- coarse grinding -- it pulverized, sintered and heat-treated. The obtained result is shown in Table 5 (a) and Table 5 (b). Or more in A= 6.2, by carrying out compound addition of Co and the Ga, A= 6.6 or more, high coercive force is acquired and, in the case of Nd-Fe-B the system of 3 yuan, a high property is acquired to most of 1Hc and (BH) max being zero. It became a cause that Nd rich phase committed as the liquid phase in a sintering process by oxidation of Nd or more in A= 6.2 decreases, and the Nd-Fe-B system of 3 yuan has barred generating of coercive force. . On the other hand, in Co and Ga compound addition, it works as the liquid phase instead of being Nd to which Ga

oxidized, and high coercive force is generated.

[0022]

[Table 5]

(a) $\text{Nd}(\text{Fe}_{0.7}\text{Co}_{0.2}\text{B}_{0.08}\text{Ga}_{0.02})_A$ 磁石の磁気特性

磁気特性 \ A	3.7	4.0	5.6	6.6	7.5	7.7
$4\pi I_r$ (KG)	9.2	10.4	12.25	12.7	13.8	14.0
H_c (KOE)	17.5	17.3	15.4	12.0	10.7	5.9
$(BH)_{\max}$ (MGOE)	19.2	25.0	35.8	37.1	45.6	15.8

(b) $\text{Nd}(\text{Fe}_{0.72}\text{B}_{0.08})_A$ 磁石の磁気特性 (比較例)

磁気特性 \ A	5.6	5.8	6.0	6.2	6.4	6.6
$4\pi I_r$ (KG)	13.04	13.2	13.4	13.6	13.7	13.8
H_c (KOE)	10.0	9.3	9.0	0	0	0
$(BH)_{\max}$ (MGOE)	40.2	41.3	42.6	0	0	0

[0023] (Example 4) 5.5 ($z=0-0.18$) -- by the same approach as an example 1, it was dissolved and ground, and was fabricated and the alloy was sintered ($\text{Fe}_{0.86}\text{-zCo}_{0.06}\text{B}_{0.08}\text{Ga}_z$). ($\text{Nd}_{0.8}\text{Dy}_{0.2}$) Furthermore, after heating maintenance of 900 degree-Cx 2 hours, after cooling to ordinary temperature by 1.5 degrees C / min, aging treatment of 580 degree-Cx 1 hour was performed in Ar air current, and it cooled underwater. The acquired magnetic properties are shown in Table 6, and the irreversible demagnetizing factor by 220-degree-C heating is shown in Table 7. It turns out that I_Hc goes up sharply although $4\pi I_r$ and $(BH)_{\max}$ fall by addition of Ga, and thermal resistance is also improving. Since $4\pi I_r$ will decrease notably if effectiveness is accepted by 0.001 and 0.15 is exceeded, it is more desirable to be referred to as $0.001 \leq z \leq 0.15$, $0 < z \leq 0.15$ is desirable, and especially the thing set to $0.005 \leq z \leq 0.05$ is [as for the addition z of Ga, it is still more desirable to be referred to as $0.002 \leq z \leq 0.10$, and] desirable [the addition].

[0024]

[Table 6]

(Nd _{0.9} Dy _{0.1}) (Fe _{0.845-z} Co _{0.06} B _{0.08} Ga _z) _{5.5}				
z	4πIr (G)	μHc (Oe)	τHc (Oe)	(BH) max (MGoe)
0	11050	10700	22500	29.5
0.001	11000	10650	23200	29.6
0.002	10900	10600	23500	28.8
0.005	10740	10400	25200	27.9
0.01	10600	10200	26500	27.2
0.05	9400	9600	27200	20.1
0.10	8900	8600	> 28000	18.9
0.15	8000	7800	> 28000	15.3
0.18	7200	7600	> 28000	11.0

[0025]

[Table 7]

(Nd _{0.9} Dy _{0.1}) (Fe _{0.845-z} Co _{0.06} B _{0.08} Ga _z) _{5.5}	
z	220℃加熱による不可逆減磁率(%, Pc=-2)
0	10.1
0.001	9.3
0.002	7.5
0.005	5.1
0.01	2.7
0.05	1.9
0.10	0.3
0.15	0.1
0.18	0.1

[0026] (Example 5) 5.5 (z=0-0.06) -- by the same approach as an example 1, it was dissolved, ground and fabricated, and was sintered and the alloy was heat-treated (Fe_{0.845-z}Co_{0.06}B_{0.08}Nb_{0.015}Ga_z). (Nd_{0.9}Dy_{0.1}) The acquired magnetic properties are shown in Table 8, and the irreversible demagnetizing factor by 220-degree-C heating is shown in Table 9. When there are few amounts of Dy permutations, it turns out that thermal stability improves by addition of Ga. Moreover, the addition of Ga is 0. When effectiveness is accepted by 0.001 and 0.15 is exceeded, it turns out that 4πilr decreases remarkably. Therefore, as for the addition z of Ga, it turns out that it is more desirable to be referred to as 0.001≤z≤0.15, 0<z≤0.15 is desirable, and especially the thing set to 0.005≤z≤0.05 is [it is still more desirable to be referred to as 0.002≤z≤0.10, and] desirable.

[0027]

[Table 8]

$$(Nd_{0.9} Dy_{0.1}) (Fe_{0.845-R} Co_{0.04} B_{0.02} Nb_{0.015} Ga_R)_{5.5}$$

z	$4\pi Ir$ (G)	BH_c (Oe)	$1H_c$ (Oe)	$(BH)_{max}$ (MGOe)
0	11850	11550	15200	34.1
0.001	11800	15200	16700	33.8
0.002	11670	11440	17400	32.4
0.005	11580	11260	18760	32.0
0.01	11400	11000	19800	31.6
0.05	10550	10100	> 28000	26.9
0.10	10000	9880	> 28000	25.2
0.15	8550	8320	> 28000	22.4
0.18	7560	7240	> 28000	20.8

[0028]

[Table 9]

$$(Nd_{0.9} Dy_{0.1}) (Fe_{0.845-R} Co_{0.04} B_{0.02} Nb_{0.015} Ga_R)_{5.5}$$

z	220℃加熱による不可逆減磁率 (% , $P_c = -2$)
0	38.1
0.001	34.4
0.002	32.6
0.005	29.7
0.01	20.3
0.05	0.7
0.10	0.6
0.15	0.6
0.18	0.5

[0029]

[Effect of the Invention] As mentioned above, as shown in the example As opposed to coercive force decreasing remarkably, since it is sintered after it became a cause that R rich phase committed as the liquid phase in a sintering process by oxidization of the rare earth elements R contained in the conventional R-Fe-B system sintered magnet decreases and content R minutes which is not oxidized [effective] have run short Since Ga contained so that lack of effective non-oxidized content R minutes may be compensated in a sintering process in this invention magnet exists as the liquid phase and sintering advances, very high $1H_c$ is discovered, it is conspicuous, and good heat stability can be acquired.

[Translation done.]

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DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]

[Drawing 1] It is drawing showing the irreversible demagnetizing factor to whenever [stoving temperature / of Nd-Fe-B, Nd-Dy-Fe-B, and a Nd-Fe-B-Ga magnet].

[Drawing 2] It is drawing showing the irreversible demagnetizing factor to whenever [stoving temperature / of Nd-Fe-Co-B, Nd-Dy-Fe-Co-B, and a Nd-Fe-Co-B-Ga magnet].

[Translation done.]

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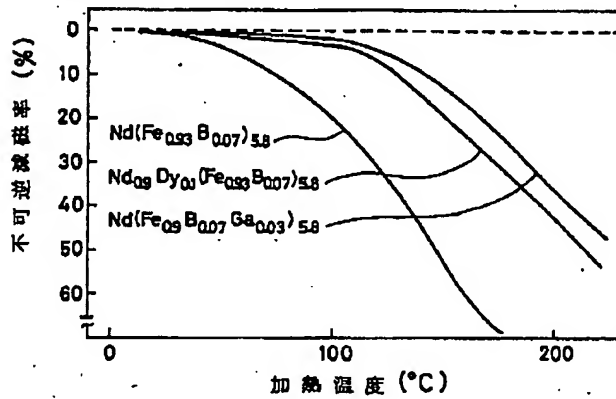
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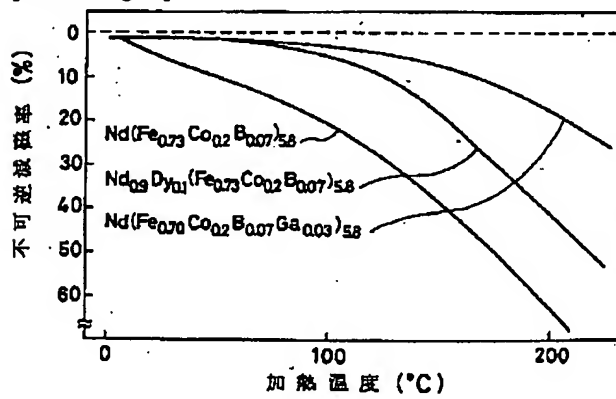
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DRAWINGS

[Drawing 1]



[Drawing 2]



[Translation done.]